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Claims

[c1] What is claimed is:

1. A bandgap reference circuit comprising:
an operational amplifier (62, 82) having a positive input end, a negative input end, and an output end;
a first transistor (M1, M1) having a source connected to a first voltage and a drain connected to the positive input end and separately to a first node (n1) through a first resistor (R3);
a second transistor (M2, M2) having a source connected to the first voltage and a drain connected to a second node (n2) through a second resistor (R4), the second node (n2) being connected to the negative input end; a gate of the second transistor (M2, M2) connected to a gate of the first transistor (M1, M1) and the output of the operational amplifier (62, 82);
a third resistor (R1a) and a fourth resistor (R1b) connected in series at the first node (n1), the third and fourth resistors (R1a, R1b) connected in parallel with a first diode (Q1, Q1) between a first current source (I1) and a second voltage; and
a fifth resistor (R2a) and a sixth resistor (R2b) connected in series at the second node (n2), the fifth and sixth re-

sistors (R2a, R2b) connected in parallel with a second diode (Q2, Q2) between a second current source (I2) and the second voltage.

[c2] 2. The bandgap reference circuit of claim 1 wherein the first and second transistors (M1, M2) are PNP transistors, the first and second diodes (Q1, Q2) are bipolar PNP transistors having collectors and bases connected to the second voltage that is ground and emitters connected to the first and second current sources (I1, I2) respectively, and the first voltage is significantly higher than ground.

[c3] 3. The bandgap reference circuit of claim 2 wherein the operational amplifier (62) comprises a third PNP transistor (M4) having a source connected to the first voltage and a drain connected to sources of fourth and fifth PNP transistors (M5, M6), drains of the fourth and fifth PNP transistors (M5, M6) are respectively connected to drains of sixth and seventh NPN transistors (M7, M8), the sixth and seventh NPN transistors (M7, M8) have sources grounded and gates mutually connected and connected to the drain of the sixth NPN transistor (M7).

[c4] 4. The bandgap reference circuit of claim 3 wherein the first voltage is between 0.85 and 1.2 volts such that an output reference voltage at the drain of the second transistor is between 198 and 214 millivolts.

[c5] 5. The bandgap reference circuit of claim 1 wherein the first and second transistors (M1, M2) are NPN transistors, the first and second diodes (Q1", Q2) are bipolar NPN transistors having collectors and bases connected to the second voltage set at significantly higher than ground and emitters connected to the first and second current sources (I1, I2) respectively, and the first voltage is ground.

[c6] 6. The bandgap reference circuit of claim 5 wherein the operational amplifier (82) comprises a third NPN transistor (M4) having a source grounded and a drain connected to sources of fourth and fifth NPN transistors (M5, M6), drains of the fourth and fifth NPN transistors (M5, M6) are respectively connected to drains of sixth and seventh PNP transistors (M7, M8), the sixth and seventh PNP transistors (M7, M8) have sources connected to the second voltage and gates mutually connected and connected to the source of the sixth PNP transistor (M7).

[c7] 7. The bandgap reference circuit of claim 6 wherein the second voltage is between 0.85 and 1.2 volts such that an output reference voltage at the drain of the second transistor is between 198 and 214 millivolts.

[c8] 8. A bandgap reference circuit comprising:

an operational amplifier (62) having a positive input end, a negative input end, and an output end;
a first PNP transistor (M1) having a source connected to a first voltage significantly higher than ground and a drain connected to the positive input end and separately to a first node (n1) through a first resistor (R3);
a second PNP transistor (M2) having a source connected to the first voltage and a drain connected to a second node (n2) through a second resistor (R4), the second node (n2) being connected to the negative input end; a gate of the second transistor (M2) connected to a gate of the first transistor (M1) and the output of the operational amplifier (62);
a third resistor (R1a) and a fourth resistor (R1b) connected in series at the first node (n1), the third and fourth resistors (R1a, R1b) connected in parallel with a first diode (Q1) between a first current source (I1) and ground; and
a fifth resistor (R2a) and a sixth resistor (R2b) connected in series at the second node (n2), the fifth and sixth resistors (R2a, R2b) connected in parallel with a second diode (Q2) between a second current source (I2) and ground.

[c9] 9. The bandgap reference circuit of claim 8 wherein the first and second diodes (Q1, Q2) are bipolar PNP transis-

tors having collectors and bases connected to ground and emitters connected to the first and second current sources (I1, I2) respectively.

[c10] 10. The bandgap reference circuit of claim 9 wherein the operational amplifier (62) comprises a third PNP transistor (M4) having a source connected to the first voltage and a drain connected to sources of fourth and fifth PNP transistors (M5, M6), drains of the fourth and fifth PNP transistors (M5, M6) are respectively connected to drains of sixth and seventh NPN transistors (M7, M8), the sixth and seventh NPN transistors (M7, M8) have sources grounded and gates mutually connected and connected to the drain of the sixth NPN transistor (M8).

[c11] 11. The bandgap reference circuit of claim 10 wherein the first voltage is between 0.85 and 1.2 volts such that an output reference voltage at the drain of the second transistor is between 198 and 214 millivolts.

[c12] 12. A bandgap reference circuit comprising:
an operational amplifier (82) having a positive input end, a negative input end, and an output end;
a first NPN transistor (M1) having a source connected to ground and a drain connected to the positive input end and separately to a first node (n1) through a first resistor (R3);

a second NPN transistor (M2) having a source connected to ground and a drain connected to a second node (n2) through a second resistor (R4), the second node (n2) being connected to the negative input end; a gate of the second transistor (M2) connected to a gate of the first transistor (M1) and the output of the operational amplifier (82);

a third resistor (R1a) and a fourth resistor (R1b) connected in series at the first node (n1), the third and fourth resistors (R1a, R1b) connected in parallel with a first diode (Q1) between a first current source (I1) and a second voltage set significantly higher than ground; and a fifth resistor (R2a) and a sixth resistor (R2b) connected in series at the second node (n2), the fifth and sixth resistors (R2a, R2b) connected in parallel with a second diode (Q2) between a second current source (I2) and the second voltage.

[c13] 13. The bandgap reference circuit of claim 12 wherein the first and second diodes (Q1, Q2) are bipolar NPN transistors having collectors and bases connected to the second voltage and emitters connected to the first and second current sources (I1, I2) respectively.

[c14] 14. The bandgap reference circuit of claim 13 wherein the operational amplifier (82) comprises a third NPN transistor (M4) having a source grounded and a drain

connected to sources of fourth and fifth NPN transistors (M5, M6), drains of the fourth and fifth NPN transistors (M5, M6) are respectively connected to drains of sixth and seventh PNP transistors (M7, M8), the sixth and seventh PNP transistors (M7, M8) have sources connected to the second voltage and gates mutually connected and connected to the source of the sixth PNP transistor (M7).

[c15] 15. The bandgap reference circuit of claim 14 wherein the second voltage is between 0.85 and 1.2 volts such that an output reference voltage at the drain of the second transistor is between 198 and 214 millivolts.